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Efficiencies of 30 GHz Power Generation for CLIC

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Introduction

Presented are efficiency estimations(wall plug to RF) for single bunch and 500 GeV center of mass operation, based on the two distinct methods of CLIC drive beam generation which presently are considered the most promising:

- the isochronous collector ring scheme
- the switchyard scheme

Both schemes having already been described extensively in ref.[1], only a brief outline is given here.

Efficiency estimations of earlier schemes[2], [3] form the basis for the calculations, in particular of the cryogenics consumption.

If the collider pulsing rate is 1.7 kHz, the needed mean 30 GHz power for an accelerating gradient of 80 MV/m over 6.25 km is 18.4 MW(tot. for both main linacs). The fill time of a main linac accel. structure is 11.4 ns, corresponding to four periods at 350 MHz(drive beam accel. freq.). The associated 30 GHz power level is 40 MW[6].

Isochronous Collector Ring Scheme

Description

Two continuous trains of 344 bunchlets(1 train for each drive linac, 12 nC/bunchlet) are accumulated in the collector ring during the approx. 588 μ s pulse interval of the CLIC main linac(see fig. 1). Every 8.6 μ s 4 bunchlets for each train is accelerated from the laser RF gun via the preinjector linac, bunch compressors and the SC 350

Fig. 1

Drive Beam generation using an isochronous ring to stack and thereby compress bunchlets into 30 GHz trains.

MHz linac to 3 GeV and injected into the ring.

For good acceleration efficiency(to ride on wave crests), the bunchlets are spaced by one period of 350 Mhz.

The acceleration of the total $8.3 \mu\text{C}$ charge being spread out over the $588 \mu\text{s}$ CLIC cycle, the beam loading compensation is obtained almost by simple CW power transfer to the SC cavities.

A two-frequency (350 MHz and 3.2 GHz) injection arrangement permits the stacking of the required trains with 1 cm spacing between the 344 bunchlets [4].

Longitudinal wakes in the SC 350 MHz cavities would cause for 12 nC bunchlets with $\sigma_z = 1 \text{ mm}$ a total momentum spread of 0.6 % [7].

To alleviate wake problems, an alternative implementation (not shown in fig. 1) of the collector ring foresees the stacking of four trains of 344 bunchlets of 3 nC for each drive linac during one CLIC cycle. In this case each train is used for power production only over a quarter of the drive linac and then dumped.

A sixteenfold increase in CTS R/Q (from 10 Ohm/m to 160 Ohm/m, circuit convention) would be necessary to obtain the specified 40 MW pulses from the output ports.

Wall Plug to RF Efficiency for the Isochronous Ring Scheme

Contrary to most klystrons the fraction of beam energy extractable into RF energy is not limited by space charge forces but mainly by the electron energy spreads (created inside the power extraction structures, the CLIC TRANSFER STRUCTURES [8], [9], [10], CTSs, see fig. 1).

Too large energy spreads can give rise to transverse instabilities.

The sources for unavoidable unequal decelerations in CTSs are:

- Bunchlet phase extension; $\sigma_z = 1 \text{ mm}$ corresponds to 36 degrees at 30 GHz.
- The first 86 bunchlets of a train traverse unfilled CTSs and are decelerated less than the following ones.

For simplicity and since most likely the assumed 1 mm rms bunchlet length, with the recently reduced bunchlet intensities (from 160 to 40 or even 12 and 3 nC in some cases), is pessimistic, adverse effects of the bunchlet phase extension will in the following be neglected,

As a rule of thumb, resulting from computer trackings [5], it seems that the drive beam can be decelerated and contained transversely free of losses if the ratio between highest and lowest electron energies does not exceed five.

Fig. 2a shows the energies for the 344 bunchlets at the drive linac beginning (3 GeV for all bunchlets) and at the drive linac end, where only the last 258 bunchlets have been decelerated to the minimum energy ($3 \text{ GeV}/5 = 0.6 \text{ GeV}$).

Fig. 2a

As mentioned above, the first bunchlet enters field-free CTSs and is hardly decelerated, only the 87th(after 1 fill time, 2.86 ns) experiences the full deceleration.

The drive beam to 30 GHz RF efficiency is 70 %, as can be calculated by comparing initial with final energies.

Above value can be improved by the introduction of a second collector ring(not shown in fig. 1) for the storage of 43 bunchlets at half the initial energy. These bunchlets would be added at the head of the train going into the drive linac by the aid of a non-pulsed bending magnet.

Fig. 2b

Since now the highest final energy is halved the lowest final energy can also be halved to 0.3 GeV(see fig. 2b). Above efficiency would rise to 84 %.

The most essential assumptions, leading to an overall(wall plug to RF) efficiency of 32.2 %, are shown in fig. 3.

The collector ring magnet consumption has been considered insignificant, since an injector synchrotron(of circumf. 1741

m) planned for LEP[11](but never built) would at 22 GeV only dissipate 2.2 MW. Scaling naively with the square electron energy, the CLIC collector ring(at 3 GeV) would only need 2 % of above value(44 kW). In practice it would be more, since for 3 GeV one would use less steel.

Fig. 3 **Wall plug to 30 GHz efficiency**

Continuous train of 344 bunchlets(via isochronous ring)

Drive linac efficiency_(wall to 30 GHz)=32.2 %

Switchyard Scheme

Description

The proposal is based on two groups of 11 photoinjectors and booster linacs in S-band(see fig. 4), each feeding one SC 350 MHz linac(see fig. 5).

The 11 injectors are timed to produce at the exit of the combiner dipole bunchlets spaced by 1 cm.

Fig. 4 Merging bunches in a beam switch-yard.

Furthermore, for the bunchlets to be collinear at this exit, the 11 booster linacs are spread out over an octave of output energy(25-50 MeV)

All injectors are fired twice per period of 350 MHz; enabling each switchyard to deliver a train of 22 bunchlets per such period.

The two SC linacs operate in antiphase such that from the transverse deflector(fig.4) 2 trains per 350 MHz period emerge.

Firstly 8 trains are delivered to one drive linac and then another set of 8 trains to the other drive linac.

Fourth harmonic(1.4 GHz) SC structures are inserted for wave flattening(res. error $\pm 4\%$) during the 90 deg. duration of the 22 bunchlets.

Furthermore 333 and 366 MHz SC structures compensate the beamloading of the main SC accel. cavities.

Since the drive beam consists of 8 subtrains spaced by 7 missing trains, the first bunchlets of a train will encounter somewhat empty

Fig. 5 Suggested layout of pre-injector and post-acceleration linacs. Example given is for 500 GeV centre-of-mass collider.

power extraction structures or CTSs; they will be decelerated less than the last ones.

To enable the bunchlets to reach approximately the same final energy at the drive linac end(for transverse stability), a 700 MHz SC momentum shaping string of cavities is foreseen before each drive linac(the string could also be placed in the linac middle).

Wall Plug to RF efficiency for the switchyard scheme

Fig. 6 shows the resulting energy distribution at the start of the linac and at its end.

The calculated drive beam to RF efficiency is 85 %.

Fig. 6 8 trains of 22 bunchlets

Fig. 7 yields detailed information on the evaluation of the 26.8 % overall efficiency(wall to RF).

Fig. 7 Wall plug to 30 GHz efficiency

Two switchyards + two linacs at 350 MHz in antiphase +90 deg. phase extension wave flattening with fourth harmonic:

Overall efficiency = 26.8 %

Conclusions

The best overall efficiency of 32.2 % is offered by the scheme based on the isochronous ring. Its feasibility within its stringent specification (insignificant bunchlet lengthening over 86 turns) remains to be demonstrated.

The switchyard scheme with 26.8 % efficiency suffers from large cryogenics losses due to a large amount of cryogenic cavities.

Both schemes are adaptable to multibunching operation, where several fills of the CLIC main linac cavities are necessary. Above overall efficiencies are hardly changed, if the collider pulsing rate is reduced in proportion with the number of fills.

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